BRIGHTENING AND VOLATILE DISTRIBUTION WITHIN SHACKLETON CRATER OBSERVED BY THE LRO LASER ALTIMETER. D. E. Smith[1], M. T. Zuber[1], J. W. Head[2], G. A. Neumann[3], E. Mazarico[1, 3], M. H. Torrence[4, 3], O. Aharonson[5], A. R. Tye[2], C. I. Fassett[2], M. A. Rosengurg[5], and H. J. Melosh[6], [1]Dept Earth Atmospheric and Planetary Sciences, MIT, Cambridge, MA 02139, (smithde@mit.edu) [2]Dept Geological Sciences, Brown University, Providence, RI 02912, [3]Solar System Exploration Division, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, [4]SGT, Inc., Greenbelt, MD 20770, [5]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, [6]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907.

Introduction: Shackleton crater, whose interior lies largely in permanent shadow, is of interest due to its potential to sequester volatiles. Observations from the Lunar Orbiter Laser Altimeter onboard the Lunar Reconnaissance Orbiter have enabled an unprecedented topographic characterization, revealing Shackleton to be an ancient, unusually well-preserved simple crater whose interior walls are fresher than its floor and rim. Shackleton floor deposits are nearly the same age as the rim, suggesting little floor deposition since crater formation over 3 billion years ago. At 1064 nm the floor of Shackleton is brighter than the surrounding terrain and the interiors of nearby craters, but not as bright as the interior walls. The combined observations are explainable primarily by downslope movement of regolith on the walls exposing fresher underlying material. The relatively brighter crater floor is most simply explained by decreased space weathering due to shadowing, but a 1-mm-thick layer containing ~20% surficial ice is an alternative possibility [1].

Analysis: Shackleton crater is situated nearly coincident with the Moon's south pole, and because the lunar equator is inclined only 1.5° from the ecliptic, the crater cavity receives almost no direct sunlight. A perennial cold trap [2, 3], Shackleton represents a promising candidate for sequestered volatiles. However, previous orbital and Earth-based radar mapping and orbital optical imaging have yielded conflicting interpretations about the existence, distribution and nature of volatiles. Detailed study of the topography of Shackleton offers the opportunity to improve understanding of processes that operate in permanently shadowed regions. Crater geometry, age and preservation state are relevant for understanding the accumulation and preservation of volatiles as well as processes that modify the lunar surface over geologic timescales.

The analysis uses observations from the Lunar Orbiter Laser Altimeter (LOLA) [4], an instrument on NASA's Lunar Reconnaissance Orbiter (LRO) mission. LOLA is a five-beam laser altimeter that operates at a wavelength of 1064.4 nm with a 28-Hz pulse repetition rate. From LRO's mapping orbit, the instrument illuminates 5-m-diameter spots on the lunar surface, returning up to 140 measurements of elevation per second; the five profiles enable characterization of bi-directional slopes over various baselines, and roughness from averaging of pulse elevations. In addition, from the spreading of backscattered laser pulses, LOLA obtains the root mean square (RMS) roughness of the surface within laser footprints. Finally, from the ratio of received to transmitted laser energy, LOLA measures the reflectance of the lunar surface at zero phase angle at the laser wavelength within laser spots.

Parameter	Value
lat, center of rim	-89.655
long, center of rim, E	129.174
lunar radius, floor center, km	1734.63
mean crater diameter at rim, km	21
mean depth, rim-floor km	4.1±0.05
mean rim height above datum, km	1.3
range of floor topography, km	~0.210
d/D, average rim to average floor	0.195±0.025

Table 1: Location and size of Shackleton crater

As of 1 December 2011, the LOLA instrument has accumulated more than 5.1 billion elevation measurements. Because Shackleton lies nearly at the pole, where the LOLA coverage is densest, it is possible to construct a digital elevation model of unprecedented spatial resolution and radial accuracy. Over 5000 LOLA tracks referenced to the Moon's center of mass via precision orbits determined from radio tracking aided by Earth-based laser tracking were converted to topography. Track segments within the area of interest were geometrically corrected at orbit crossover points.

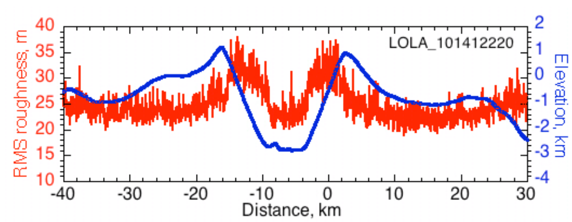

Figure 1: Profile of elevation (in blue) and RMS roughness (in red), the latter derived from the spreading of laser pulses.

The floor of Shackleton can be divided into two regions, a flat portion and an elevated terrain. The ele-

vated area is smoother than the flat region at small scales and has a relief of ~210 m (Table 1) and the highest-local slope of any of the floor deposits is ~25^{o}, which is below the angle of repose. Two areas of the floor show fan-shaped structures consisting of material that has been transported downslope from the interior walls.

Shackleton's crater floor is darker than its interior walls, but brighter than the surrounding terrain. Impingement of the solar wind produces "space weathering" of exposed materials [5]. Volatile deposition is an alternative possibility. If water ice has a reflectance twice that of the lunar regolith the measured reflectance of the floor can be explained by a micron-thick surface layer of 22% ice mixed with rock [6]. The higher reflectance of the walls than the floor is most-likely downslope movement of regolith material that has exposed brighter underlying material and is consistent with the observed slopes near the angle of repose.

References:

[1] Zuber, M. T. et al, (2012) submitted. [2] Watson, K., Murray, B. C. & Brown, H. (1961) *J. Geophys. Res.* **66**, 3033-3045. [3] Arnold, J. R. (1979) *J. Geophys. Res.* **84**, 5659-5668. [4] Smith, D. E. *et al.* (2010) *Space Sci. Rev.* **150**, 209-241. [5] Hapke, B. (2001) *J. Geophys. Res.* **106**, 10,039-010.073. [6] Pieters, C. M. *et al.*. (2009) *Science* **326**, 568-572.